An Assessment of the Current LEO Debris Environment and the Need for Active Debris Removal

J.-C. Liou
NASA Orbital Debris program Office, Johnson Space Center, Houston, TX 77058, USA
jer-chyi.liou-1@nasa.gov

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The anti-satellite test on the Fengun-1C weather satellite in early 2007 and the collision between Iridium 33 and Cosmos 2251 in 2009 dramatically altered the landscape of the human-made orbital debris environment in the low Earth orbit (LEO). The two events generated approximately 5500 fragments large enough to be tracked by the U.S. Space Surveillance Network. Those fragments account for more than 60% increase to the debris population in LEO. However, even before the ASAT test, model analyses already indicated that the debris population (for those larger than 10 cm) in LEO had reached a point where the population would continue to increase, due to collisions among existing objects, even without any future launches. The conclusion implies that as satellites continue to be launched and unexpected breakup events continue to occur, commonly-adopted mitigation measures will not be able to stop the collision-driven population growth. To remediate the debris environment in LEO, active debris removal must be considered.

This presentation will provide an updated assessment of the debris environment after the Iridium 33 / Cosmos 2251 collision, an analysis of several future environment projections based on different scenarios, and a projection of collision activities in LEO in the near future. The need to use active debris removal to stabilize future debris environment will be demonstrated and the effectiveness of various active debris removal strategies will be quantified.

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J.-C. Liou, PhD
NASA Orbital Debris Program Office
Johnson Space Center, Houston, Texas

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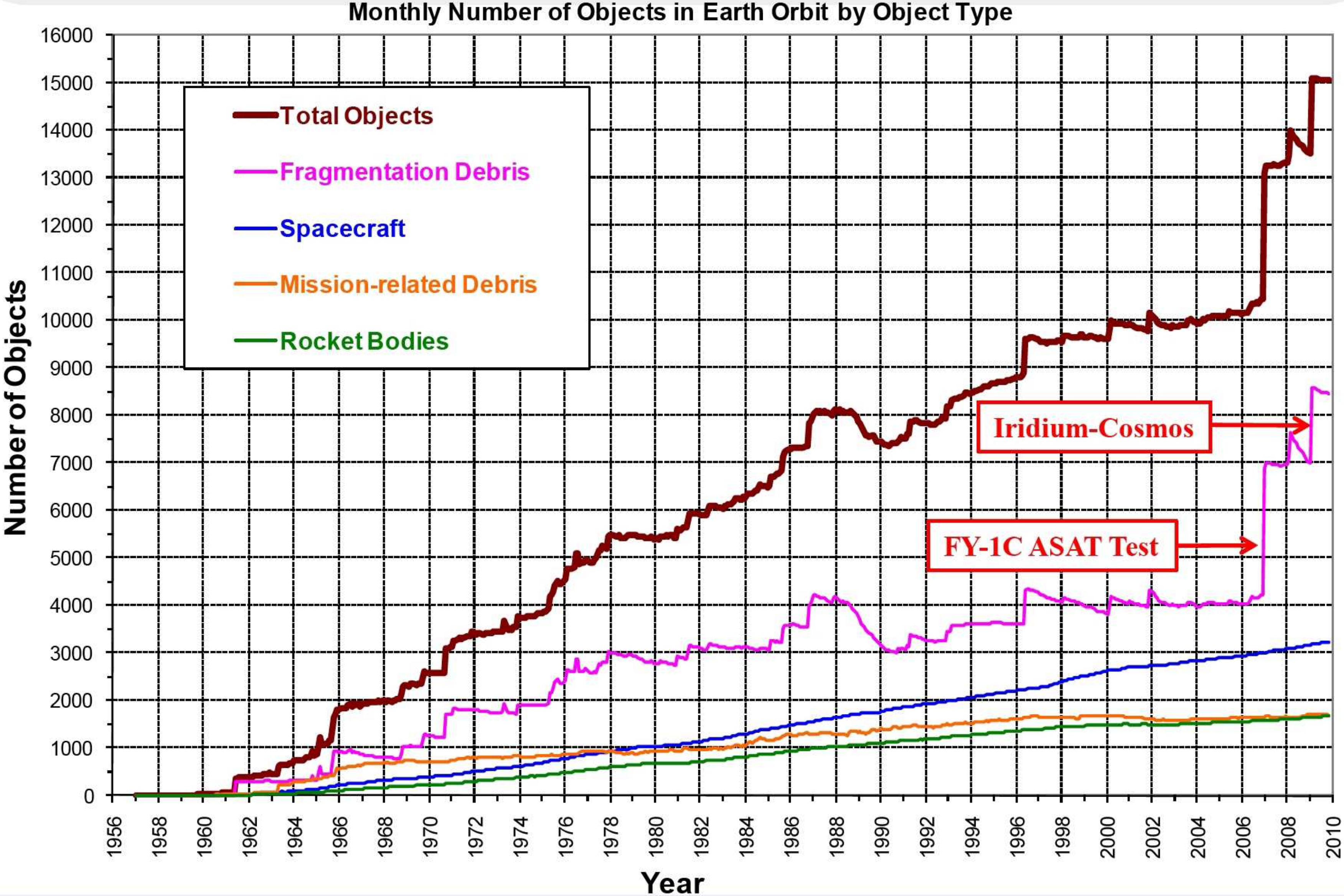
Outline

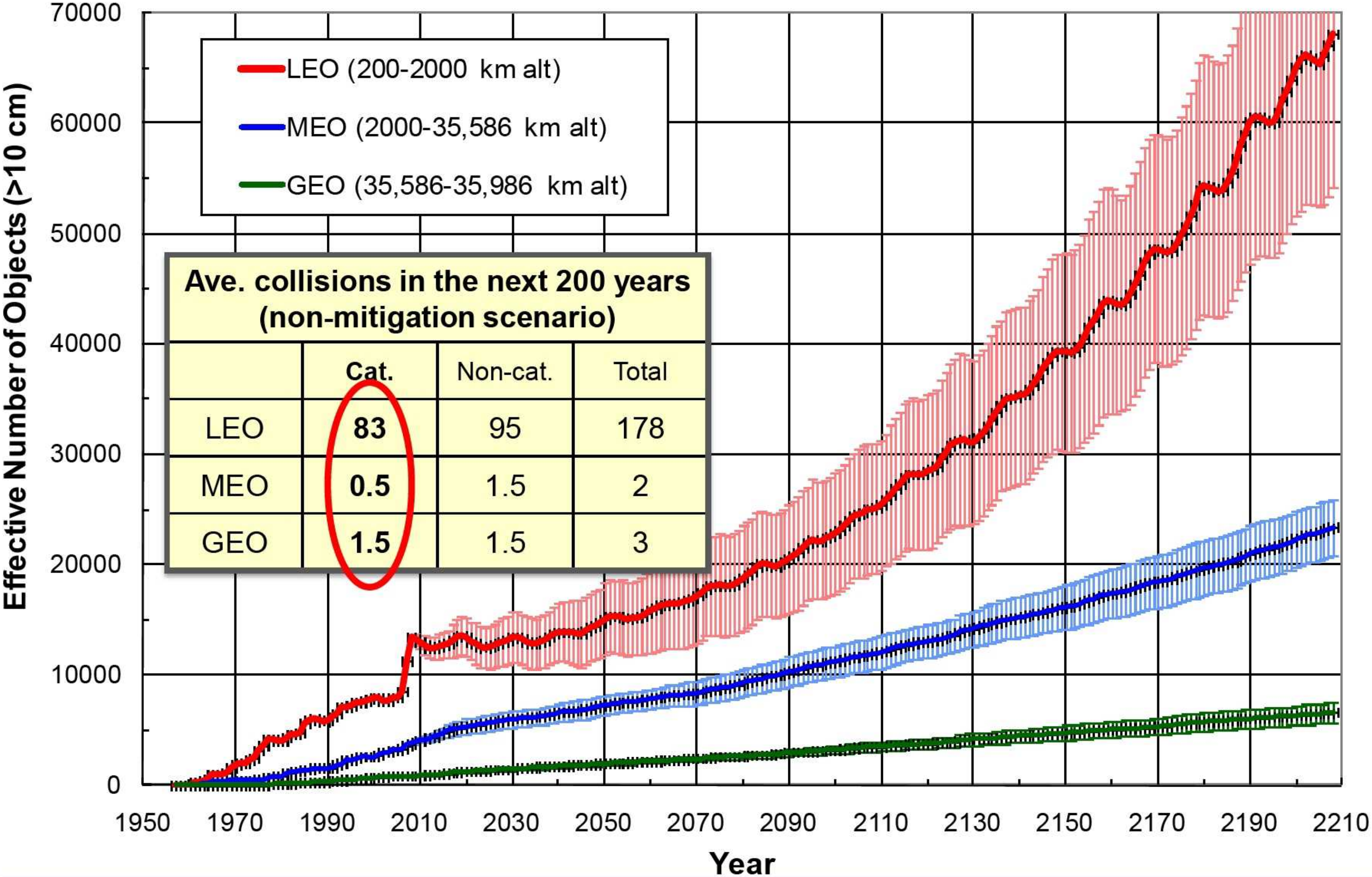
- **An assessment of the current debris environment**
  - Focus the discussion on ≥10 cm objects
  - Limit the future projection to 200 years
  - Use the NASA orbital debris evolutionary model, LEGEND (an LEO-to-GEO Environment Debris model), for the studies
- **Beyond the currently-adopted mitigation measures**
  - Is there a need to consider active debris removal?
- **Active debris removal activities**
  - NASA-DARPA Debris Removal Conference, ISTC Space Debris Mitigation Workshop, European Workshop on Active Debris Removal, *etc*.

Growth of the Historical Debris Populations



Projected Growth of the Future Debris Populations

Non-Mitigation Projection (averages and 1-σ from 100 MC runs)



Ave. collisions in the next 200 years (non-mitigation scenario)

	Cat.	Non-cat.	Total
LEO	**83**	95	178
MEO	**0.5**	1.5	2
GEO	**1.5**	1.5	3

Assessments of the Simulation Results

- **LEO: the non-mitigation scenario predicts the debris population (≥10 cm objects) will have a rapid non-linear increase in the next 200 years**
  - A well-known trend
  - This trend was the motivation for developing the currently-adopted mitigation measures more than 10 years ago

- **MEO and GEO: the non-mitigation scenario predicts a moderate population growth**
  - With just a few accidental collisions between ≥10 cm objects in the next 200 years
  - The currently-adopted mitigation measures will further limit the population growth in key regions
  - Active debris removal is not a priority

Will the Commonly-Adopted Mitigation Measures Stabilize the Future LEO Environment?

An Assessment of the LEO Environment

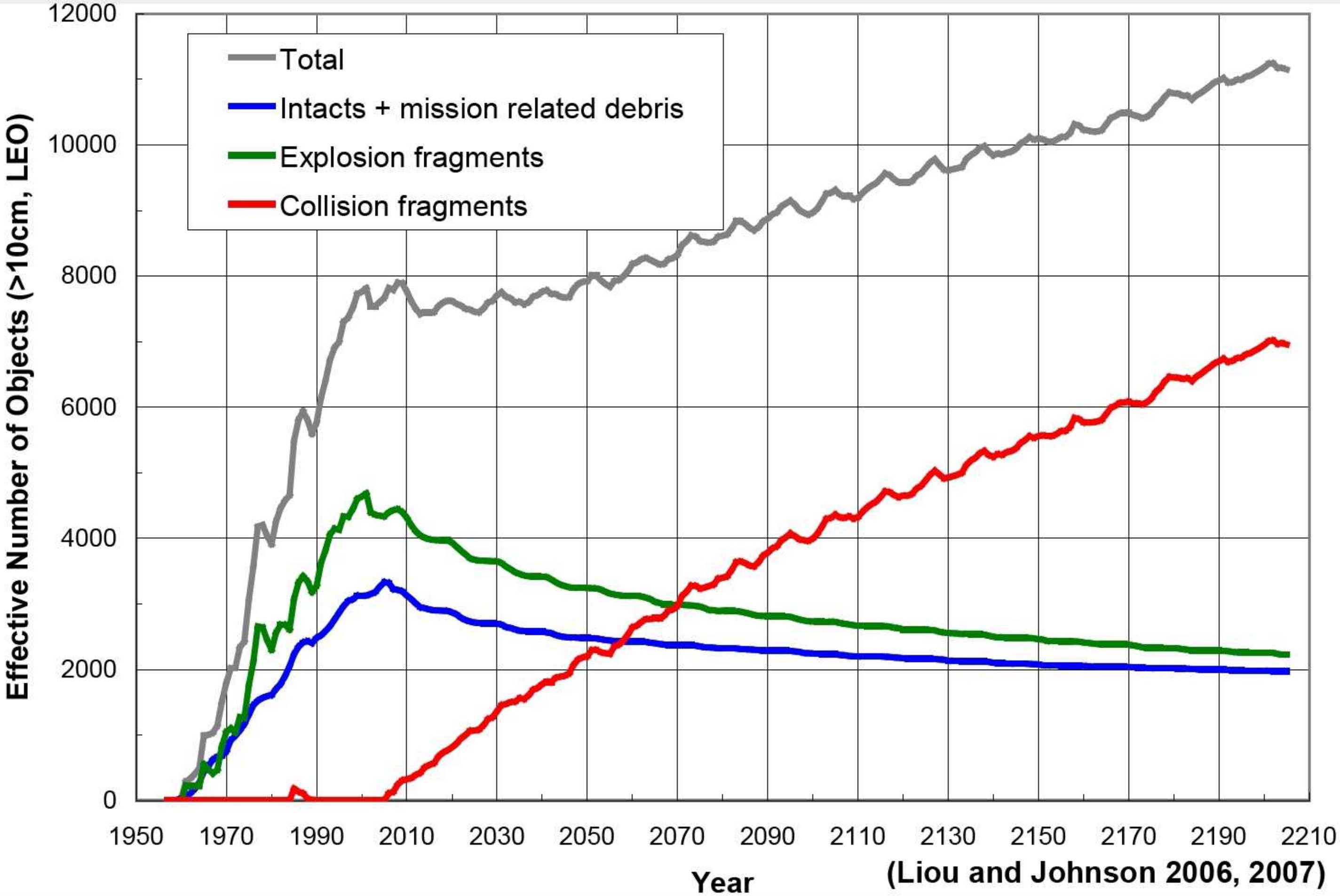
- **A major LEGEND study on the debris environment was conducted in 2005**
  - "The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future."
  - "Only remediation of the near-Earth environment – the removal of existing large objects from orbit – can prevent future problems for research in and commercialization of space."

  - Liou and Johnson, ***Science***, 20 January 2006

Previous Studies – It Will Happen

- **Increasing debris population may lead to collision cascade (Kessler and Cour-Palais 1978; Eichler and Rex 1989)**
- **The “critical density” concept was pioneered by Kessler (1991) to describe the threshold of the instability**
- **Various analytical, semi-analytical, and numerical studies, based on different model assumptions and different future traffic rates (constant, increased, with or without postmission disposal, *etc*.) have been performed**
  - Su (1993); Rossi *et al*. (1994); Anselmo *et al*. (1997); Kessler (2000); Kessler and Anz-Meador (2001); Krisko *et al*. (2001)
- **These study results indicate that, as the space activities continue, the LEO debris populations at some altitudes are unstable and population growth may be inevitable**

The 2005 LEGEND Study – It Already Happened!
(No New Launches Beyond 1/1/2006)



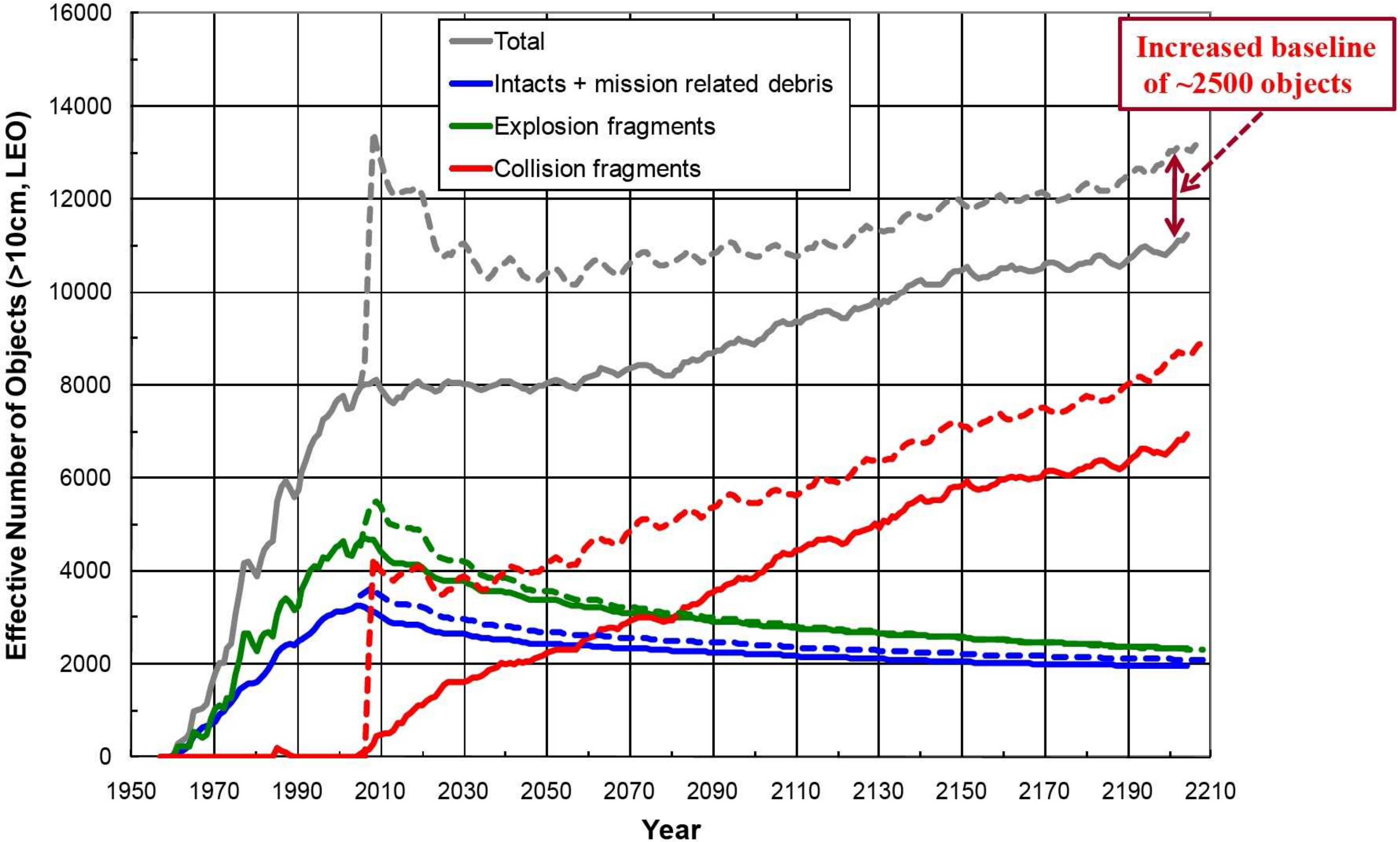
(Liou and Johnson 2006, 2007)

- Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant
- Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions

A Realistic Assessment

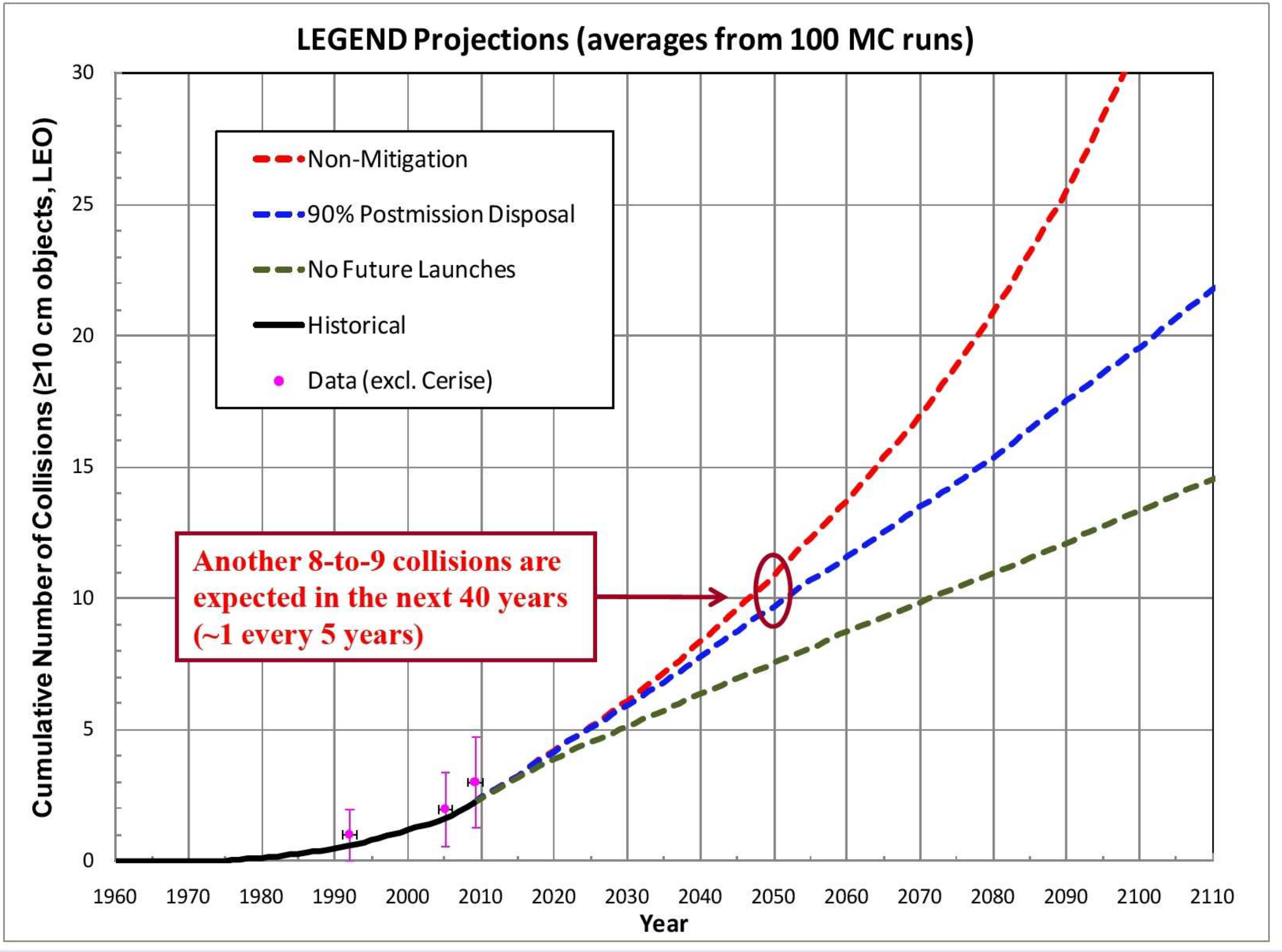
- **In reality, the situation will be worse than the "no new launches" scenario as**
  - Satellites launches will continue
  - Major breakups may continue to occur (*e.g.*, Fengyun-1C, Briz-M, Iridium 33 - Cosmos 2251)
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening**
- **To preserve the near-Earth space for future generations, active debris removal (ADR) must be considered**

LEO Environment After FY-1C and Iridium/Cosmos Breakups



- Solid lines: 1957-to-2006, no new launches beyond 2006
- Dashed lines: 1957-to-2009, no new launches beyond 2009

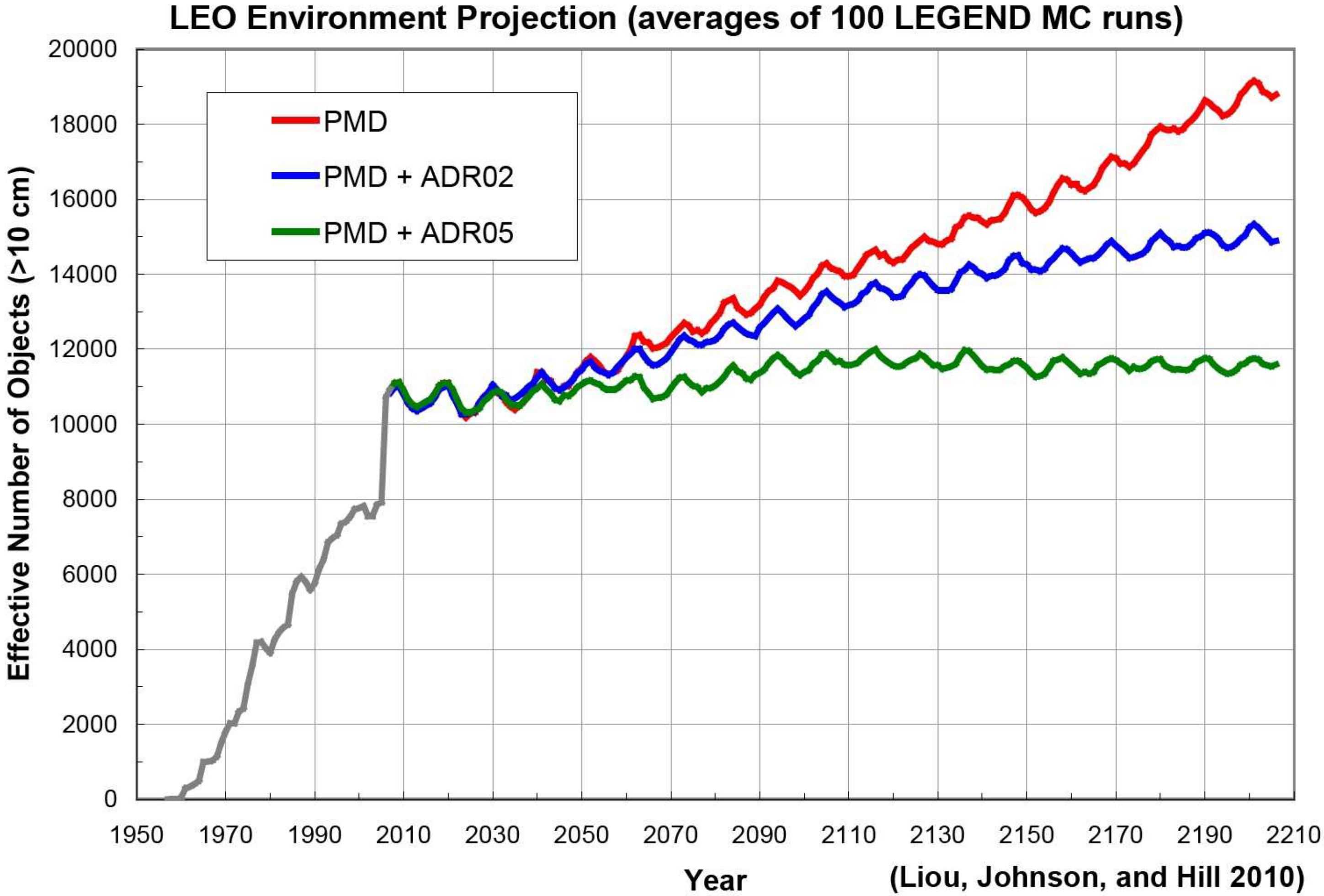
Collisions in LEO



Active Debris Removal Modeling

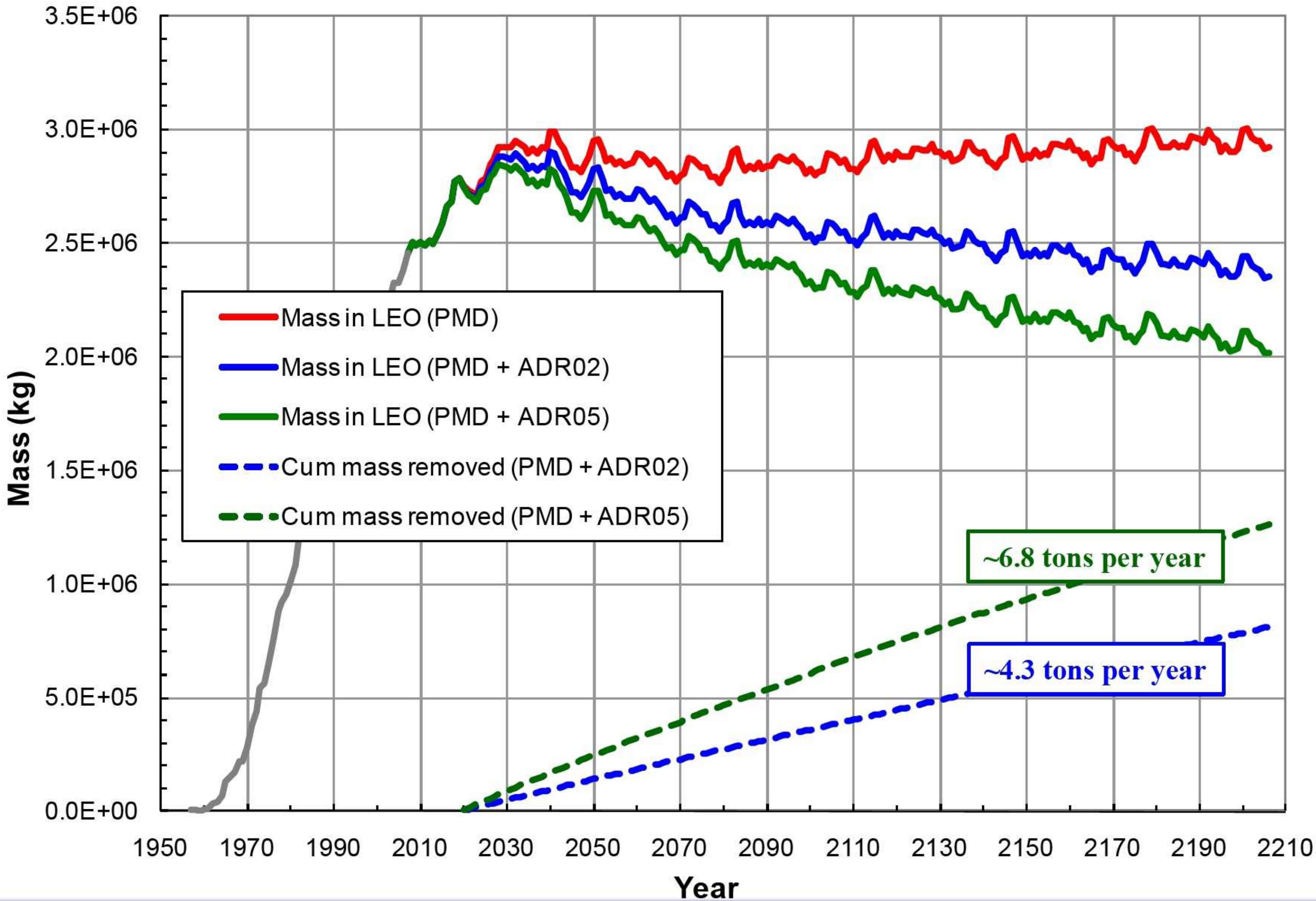
- **The NASA Orbital Debris Program Office initiated the LEGEND ADR modeling study in late 2006 to**
  - Develop simple, reliable, and objective ADR selection criteria
  - Quantify the effectiveness of different ADR scenarios
  - Explore various ADR strategies to stabilize the future debris environment
- **The results indicate that the keys to stabilizing the future LEO environment in the next 200 years are**
  - A good implementation of the commonly adopted mitigation measures (passivation, 25-year rule, *etc*.)
  - An active debris removal of about five objects per year
    - **Select RSOs with the highest [M × Pc]**
  - The environment can be better than what it is today if more than five objects per year are removed

LEO Population Control

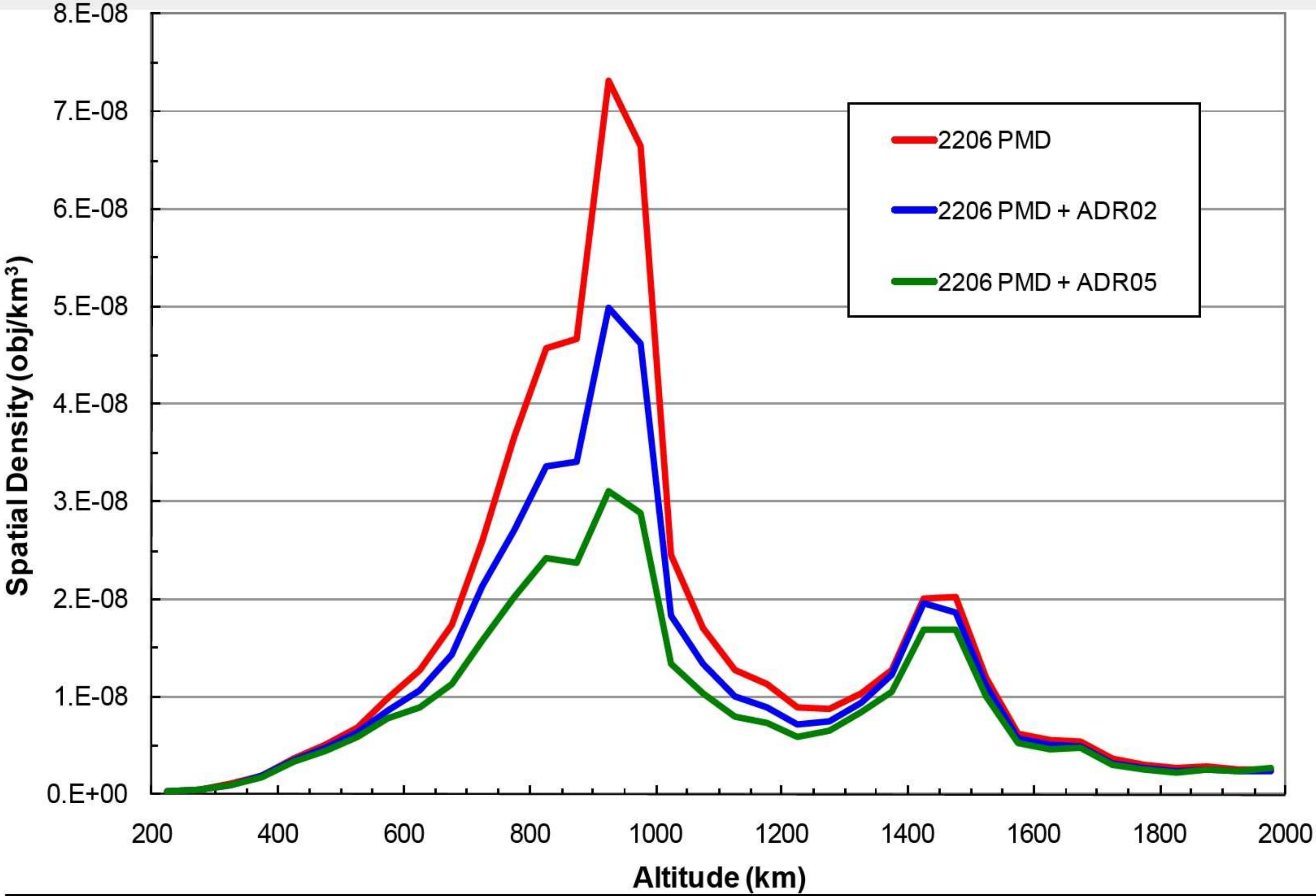


- **PMD scenario predicts the LEO populations would increase by ~75% in 200 years**
- **The population growth could be reduced by half with a removal rate of 2 obj/year**
- **LEO environment could be stabilized with a removal rate of 5 obj/year**

Mass in Orbit and Mass Removed



Spatial Density of Objects 10 cm and Larger



- **The ADR selection criterion, mass × P_c, successfully removes objects from high collision activity regions and reduces the overall population growth**

Optimize ADR Target Selection
– How to Define Mission Success?

- **Different parameters can be used to quantify the effectiveness of the ADR target selection criteria**
  - Population growth (≥10 cm or others)
  - Collision activities
  - Mass, spatial density, risks (conjunctions, damage) to selected payloads, risks to human space activities, *etc.*
- **Alternative target selection criteria (in size, altitude, inclination, class, *etc*.) may be more practical, but will need to be carefully evaluated to maximize the benefit-cost ratio of active debris removal**
- **Conjunction assessments and collision avoidance maneuvers will help**

Recent and Future Activities Related to Active Debris Removal

The International Conference on Orbital Debris Removal (Dec. 2009)

Registration

Register on-line prior to November 23, 2009 at https://www.enstg.com/signup. Enter code: INT11415

A $300 (USD) conference fee applies. Registration includes:

- Attendance at the two-and-a-half day conference
- Continental breakfast each morning
- Luncheons Tuesday & Wednesday

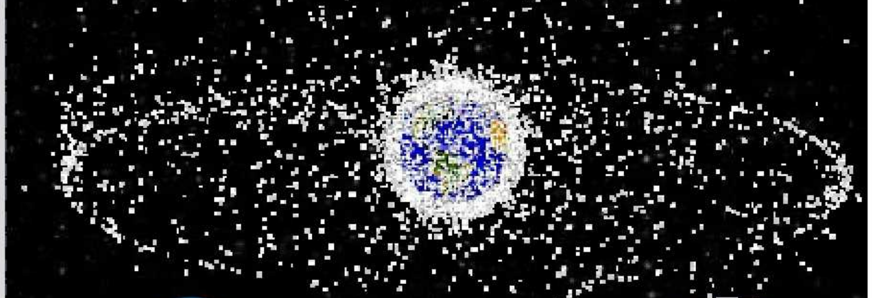
Hotel reservations can be made at the conference location while rooms last:

Westfields Marriott
14750 Conference Center Drive
Chantilly, VA 20151
Phone: 800-635-5666 (Reference: Orbital Debris Removal)
Or online at: http://www.westfieldsmarriott.com
Group code: CODCODA

Room rate for conference attendees is $149 (USD).

International Conference on Orbital Debris Removal

December 8-10, 2009



Chantilly, Virginia
USA

Call for Presentations

Attendees wishing to present an appropriate technical or scholarly briefing consistent with the conference topics may submit a 250 word abstract in English via e-mail to the selection committee at: orbitaldebrisconference@darpa.mil. Submissions must be received by October 30, 2009, and include a title and the author's name and affiliation. If your abstract is selected for presentation you will be asked to submit a full presentation prior to November 30, 2009.

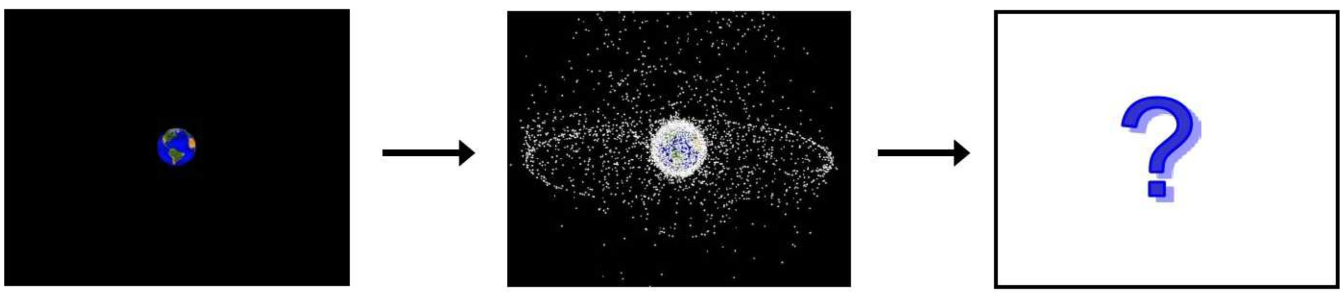
Numerous fora have been held in the past to discuss issues related to orbital debris. However, this first of its kind conference, co-hosted by the National Aeronautics and Space Administration (NASA) and the Defense Advanced Research Projects Agency (DARPA), will bring government and industry together to address the issues and challenges involved with removing manmade orbital debris from Earth orbit.

A Brief Summary of the Conference

- **The 2.5-day conference included 10 sessions**
  - Understanding the Problem; A Solution Framework; Legal & Economic Issues/Incentives; Operational Concepts; Using Environmental Forces; Capturing Objects; Orbital Transfer Solutions; Technical Requirements; In Situ vs. Remote Solutions; Laser Systems.
  - 275 participants from 10 countries
  - 52 presentations plus 4 keynote speeches
- **The conference reflected a growing concern for the future debris environment**
- **It represented the first joint effort for different communities to explore the issues and challenges of active debris removal**

Concluding Remarks

- **The challenges ahead**
  - Community recognition, consensus, and commitment
  - Technology
  - Cost
  - Ownership, legal, liability, policy, *etc*.
- **Current and future activities**
  - ISTC Space Debris Mitigation Workshop, European Workshop on Active Debris Removal, debris removal papers at upcoming COSPAR, IAC, *etc.*



Pre 1957 **2010** **2210+**

Backup Charts

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